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CIVIL EFFECTS STUDY

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EXPERIMENTAL EVALUATION OF THE FALLOUT-RADIATION PROTECTION AFFORDED BY A SOUTHWESTERN RESIDENCE

Z. Burson, D. Parry, and H. Borella

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CIVIL EFFECTS TEST OPERATIONS
U.S. ATOMIC ENERGY COMMISSION

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EXPERIMENTAL EVALUATION OF THE FALLOUT-RADIATION PROTECTION AFFORDED BY A SOUTHWESTERN RESIDENCE

By

Z. Burson, D. Parry, and H. Borella

Approved by: R. L. CORSBIE
Director
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U. S. Atomic Energy Commission

Edgerton, Germeshausen & Grier, Inc.
Santa Barbara, California
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ABSTRACT

An experimental study was conducted to determine the fallout-radiation protection afforded by a residence representative of a type of construction much in favor in the Southwest: a single-story stucco and frame house with a heavy shake roof and no basement. This study was one of many such studies sponsored by Civil Effects Test Operations, Division of Biology and Medicine, U. S. Atomic Energy Commission, for the purpose of evaluating the protection presently afforded by ordinary homes and structures against the dangers of fallout radiation.

The protection afforded by the home was determined by simulating a fallout-radiation field above and immediately surrounding the house and measuring the radiation level within. The radiation field was simulated by pumping a sealed Co^{60} source through a long length of tubing evenly distributed over the test area. Highly sensitive dose-integrating ionization chambers were used to measure the radiation level inside the structure. The test was performed rapidly, easily, and safely. Valid statistical data were obtained even though the radiation level was of such low magnitude that it was unnecessary to evacuate any of the neighboring homes.

The protection factors within the house (ratio of exposure dose rate in the open field to exposure dose rate in the structure) ranged from 2.8 to 4.4, depending on the location. The results compare favorably with those found in previous exercises under similar conditions.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to all the technical participants for their cooperation and support, which greatly contributed to the successful completion of the experiment. Also the authors gratefully acknowledge the cooperation, support, and valuable contributions made by each of the following:

R. L. Corsbie and members of the Civil Effects Test Operations staff for their over-all support of the project.

Mr. and Mrs. H. E. Grier and family, whose home was used in this study. Their cooperation allowed the study to be made easily and quickly.

R. A. Lusk of the executive office of Edgerton, Germeshausen & Grier, Inc., who handled the public-relation and information aspects of the program.

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Chapter 1

INTRODUCTION

Civil Effects Test Operations, Division of Biology and Medicine, Atomic Energy Commission, is sponsoring a program to evaluate experimentally the protection afforded by typical homes,[1,2] large structures,[3,4] and shelters[5] against the effects of fallout radiation. The study presented in this report is a part of this over-all program.

The objectives of the experiment were to measure the fallout protection afforded by a home typical of the type of construction much used in the Southwest and to demonstrate the simplicity and safety by which such measurements can be made.

H. E. Grier, EG&G, volunteered the use of his home for this study. The home is located at Parkway East, Las Vegas, Nev. It is a seven-room one-story stucco and frame house with a heavy shake roof and no basement. The floor space is approximately 2200 sq ft. The rather large back yard contains a swimming pool. Views of the house and yard are presented in Figs. 1.1 to 1.4. A 4-ft-high rock-veneer surface partially covers the front of the house. A brick fireplace is located near one corner of the house. An approximate floor plan showing the location of the rock veneer and the fireplace is presented in Fig. 4.1. Accurate architectural drawings were not available.

REFERENCES

1. J. A. Auxier et al., Experimental Evaluation of the Radiation Protection Afforded by Residential Structures Against Distributed Sources, Report CEX-58.1, January 1959.
2. T. D. Strickler and J. A. Auxier, Experimental Evaluation of the Radiation Protection Afforded by Typical Oak Ridge Homes Against Distributed Sources, Report CEX-59.13, April 1960.
3. J. F. Batter, Jr., et al., An Experimental Evaluation of the Radiation Protection Afforded by a Large Modern Concrete Office Building, Report CEX-59.1, January 1960.
4. Z. G. Burson et al., Evaluation of the Fallout Protection Afforded by Brookhaven National Laboratory Medical Research Center, Report CEX 60.1, October 1961.
5. Z. Burson and H. Borella, Experimental Evaluation of the Radiation Protection Provided by an Earth-covered Shelter, Report CEX-60.6 (in preparation).

Fig. 1.1 — View of the front (east side) of the house.

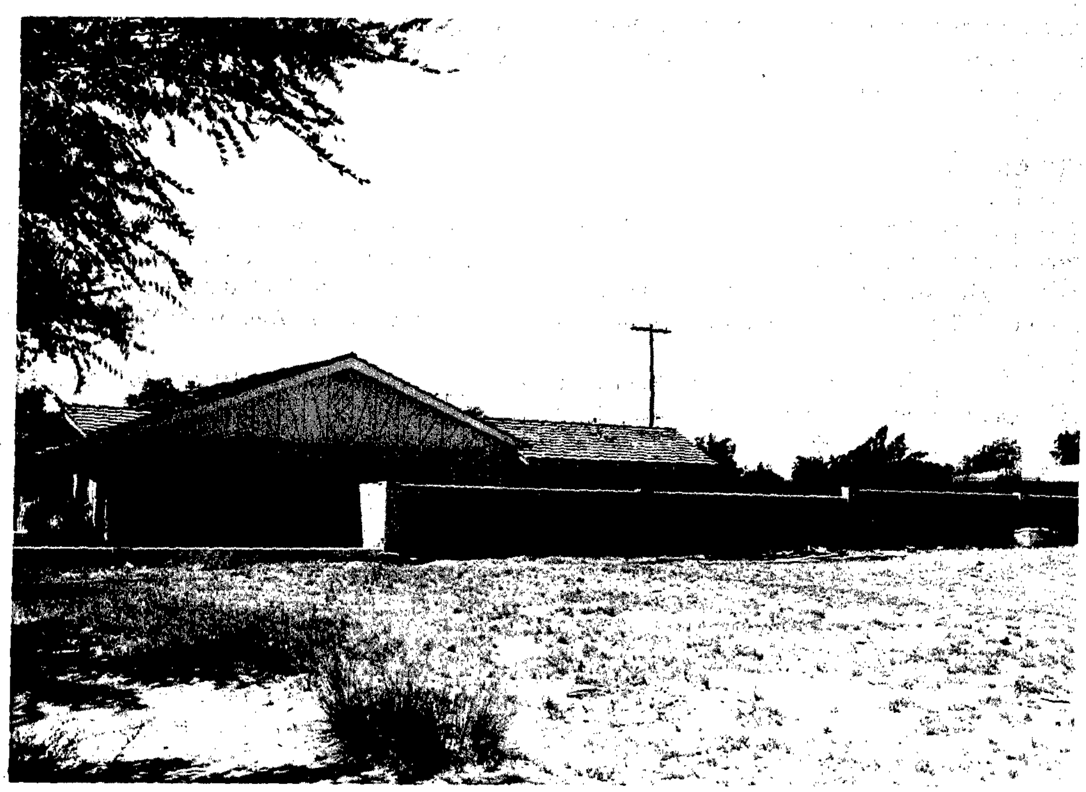

Fig. 1.2 — View of the north side of the house.

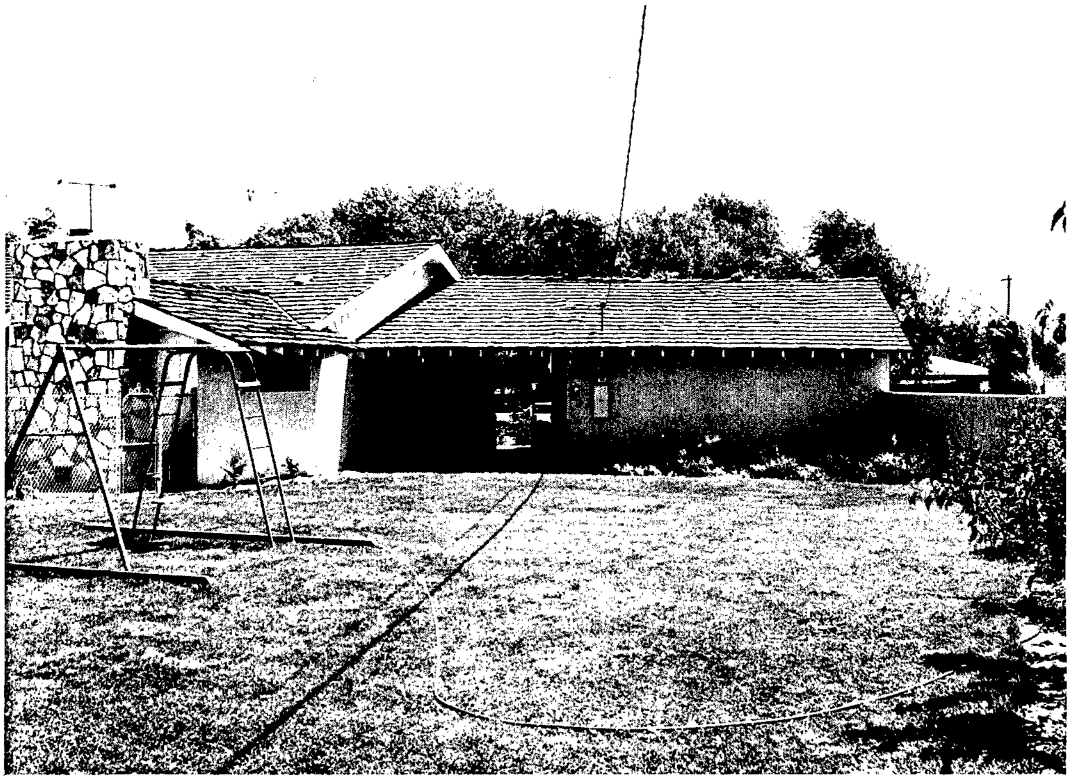

Fig. 1.3— View of the southwest side of the house.

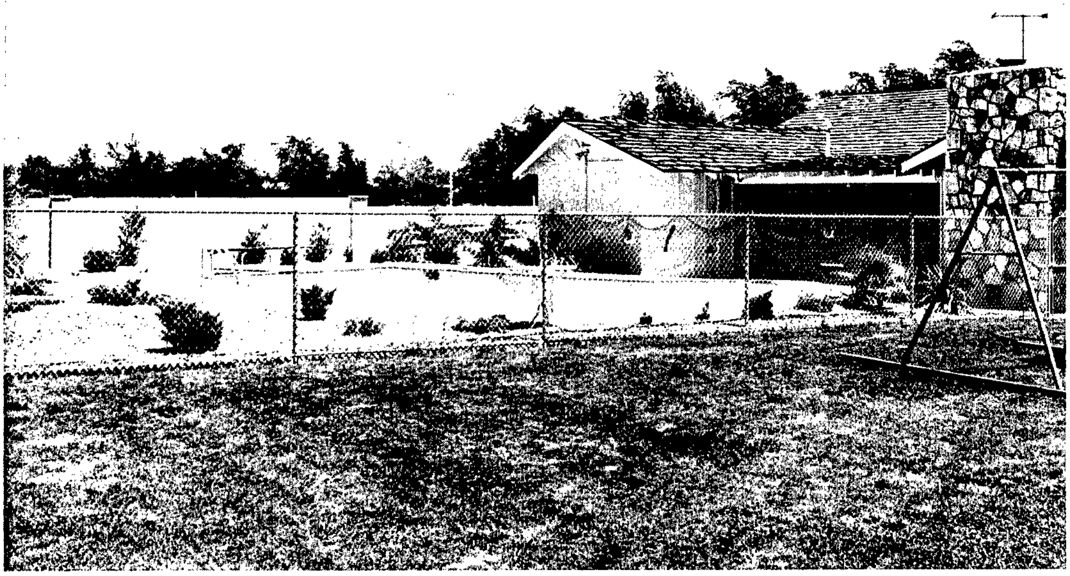

Fig. 1.4— View of the northwest side of the house.

Chapter 2

THEORY

The term "protection factor (PF)" is used to describe the protective qualities of a structure. It is defined as the ratio of the exposure dose rate 3 ft above an infinite smooth plane uniformly contaminated with radioactive material to the dose rate at any point inside the structure due to the same degree of contamination on the surrounding grounds and roof. This may be represented empirically as follows:

$$PF = \frac{D_\infty}{D_S} \tag{2.1}$$

where PF is the protection factor, D_∞ is the infinite-plane dose rate, and D_S is the dose rate at a point inside the structure.

Since it is impractical to approximate an infinite-plane radiation field for experimental measurements, it is convenient to consider the dose rate from the infinite plane to be made up of two parts:

$$D_\infty = D_1 + D_2 \tag{2.2}$$

where D_1 is the dose rate 3 ft above the center of a circular contaminated area of radius r and D_2 is the dose rate from the area outside the circle of radius r.

The dose rate D_S inside the structure can be considered to be made up of several parts:

$$D_S = R + G_1 + G_2 \tag{2.3}$$

where R is the dose rate from contamination on the roof, G_1 is the dose rate from contamination on the ground around the structure within a circular area of radius r (from center of building), and G_2 is the dose rate from the area beyond this circle.

With the above terminology the protection factor is given by

$$PF = \frac{D_1 + D_2}{R + G_1 + G_2} \tag{2.4}$$

The values of D_1, R, and G_1 can be experimentally measured, but the values of D_2 and G_2 must be calculated. A good approximation of the protection factor can be obtained by neglecting the contributions from large distances (calculated values). Accordingly,

$$PF\ (\text{approx.}) = \frac{D_1}{R + G_1} \tag{2.5}$$

where the values on the right-hand side can be experimentally measured. The value of r in determining the effective circular contaminated area depends on the operational limitations in simulating fallout radiation on the surrounding terrain.

For the study on this house, fallout radiation was simulated over an approximately square area of 11,500 sq ft. The effective radius of an equivalent circular contaminated area is 60.5 ft. It has been shown[1-4] that, for purposes of calculation, no serious error is introduced if rectangular source distributions are theoretically converted to circular source distributions. The dose rate above the center of circular contaminated areas was measured and calculated and was found to be 270 mr/hr at a height of 3 ft, a radius of 60.5 ft, and a uniform source density of 1 mc/sq ft of Co^{60} radiation.

The validity of using Co^{60} in simulating fallout radiation has been discussed in the literature.[1,3] In general, the protection factor for fission-product and Co^{60} gamma radiation should compare to within 10 per cent.[1]

REFERENCES

1. T. D. Strickler and J. A. Auxier, Experimental Evaluation of the Radiation Protection Afforded by Typical Oak Ridge Homes Against Distributed Sources, Report CEX-59.13, April 1960.
2. J. A. Auxier et al., Experimental Evaluation of the Radiation Protection Afforded by Residential Structures Against Distributed Sources, Report CEX-58.1, January 1959.
3. C. E. Eisenhauer, Analysis of Experiments on Light Residential Structures with Distributed Cobalt-60 Sources, Report NBS-6539, National Bureau of Standards, October 1959.
4. C. L. Schlemm et al., Scattered Gamma Radiation Measurements from a Co^{60} Contaminated Field, Report AFSWC-TN-59.6, Air Force Special Weapons Center, January 1959.

Chapter 3

DESCRIPTION OF EXPERIMENTAL METHOD

3.1 GENERAL DESCRIPTION

A uniform fallout-radiation field was simulated on the roof and on the ground surrounding the house out to a distance of approximately 30 ft from the edge of the structure. This field was simulated by passing a Co^{60} source through a length of tubing evenly distributed over the area. The source was circulated through the tubing at a uniform speed to simulate an area of uniformly distributed radioactive material. High-sensitivity ionization chambers were used to measure the radiation level inside the house. The dosimeters accumulated a total dose (integrated over area and time) to give the same result as would a uniform fallout-radiation field equally distributed over the same test area.

3.2 APPARATUS AND INSTRUMENTATION

The Mobile Radiological Measuring Unit (MRMU) used for this test had been used for other projects of this nature.[1,2]

The Co^{60} point source used in the MRMU is moved hydraulically. When the system is energized, the source is pumped from a shield, through the tubing, and back into the shield. Radiation detectors accumulate the radiation dose inside the test structure while the source is moving through the tubing.

The system consists of a hydraulic pumping unit, associated plastic tubing, source-position indicators, remote-control console, source shield, Co^{60} sources, and interconnecting cables. The hydraulic system and source shields are shown in Fig. 3.1.

The hydraulic system is operated from a remote-control console (Fig. 3.2). The console is in a laboratory trailer containing all the controls and indicators for the entire system. The laboratory trailer is always located far enough away from the test area that the radiation level in the trailer during the test is below AEC tolerance levels. From the console the operator can start, stop, reverse, and control the movement of the source. A series of lights on the indicator panel of the console are connected individually to magnetic indicators attached to the tubing to provide an indication of the position and direction of travel of the source at all times.

Hydraulic operation of the system is reversible, and maximum velocity can be obtained in either direction. The control system can stop the source at any given position. An emergency hand pump is provided to retrieve the source from either direction in the event of failure of the main pumping unit.

The source is conveyed by water through ½-in.-ID plastic Marlex tubing.

Measurements were made with Victoreen model 239 ionization chambers, 10 mr full scale. Victoreen model 287 minometers were used for charging and reading these dosimeters (Fig. 3.3). Calibration of a large number of these dosimeters[1] indicated a deviation of less than 10 per cent from their average at any reading for 1 to 10 mr. Also, an energy-dependence study[1] indicated a dependence of less than 10 per cent of true dose at energies as low as 40 kev.

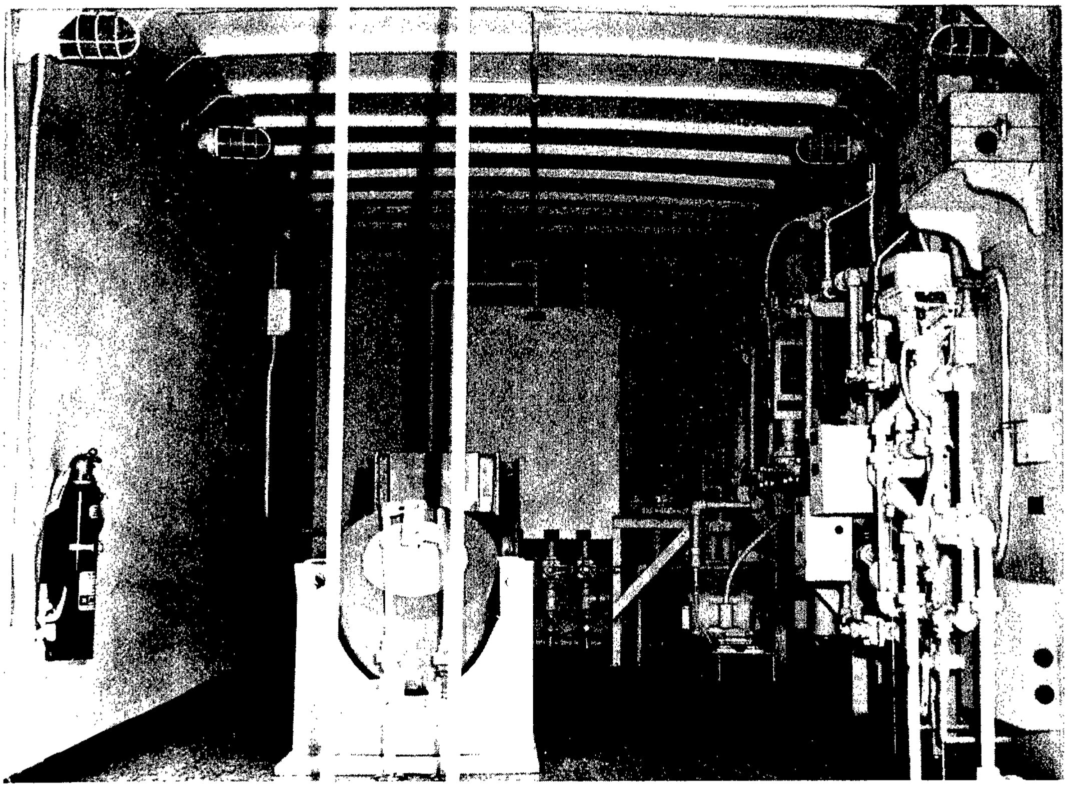

Fig. 3.1—Hydraulic system and source shields.

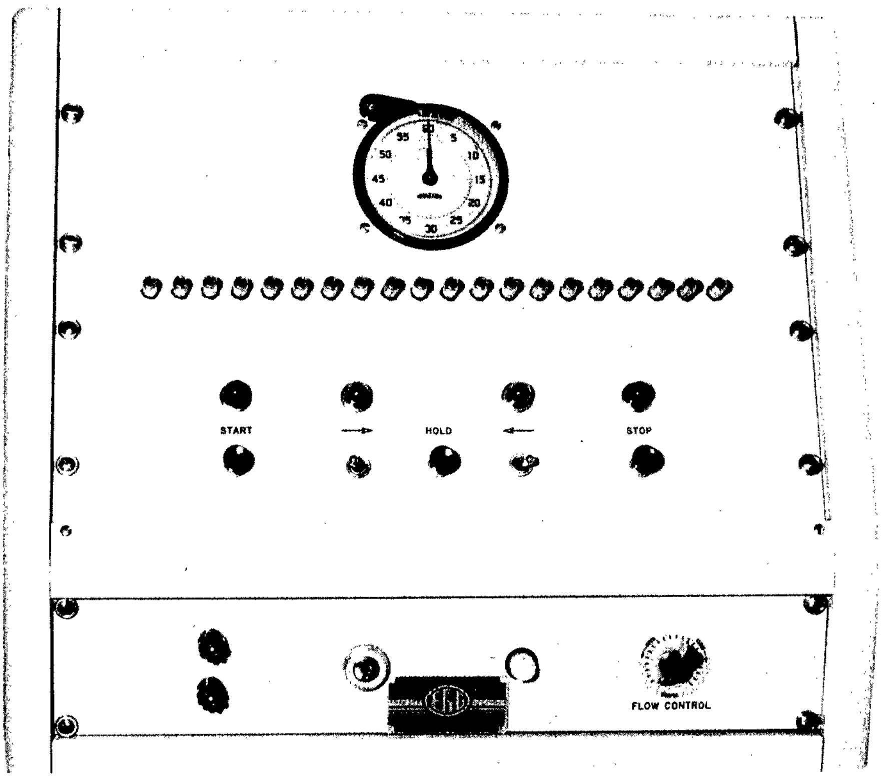

Fig. 3.2—Control console.

A 191-mc Co^{60} source was used for this experiment. The Co^{60} was encapsulated in a magnetic stainless-steel container (Fig. 3.4). The outside diameter of the container was slightly less than the inside diameter of the tubing; thus the container could pass easily through the tubing.

3.3 EXPERIMENTAL TECHNIQUE

Approximately 2300 ft of tubing was distributed over the roof of the home and on its surrounding grounds, covering a total area of 11,500 sq ft (Figs. 3.5 to 3.7.). Magnetic indicators connected to lights on the control panel were placed at strategic points on the tubing so that the operator could determine the location of the source as it passed through the tubing. The control laboratory truck containing the control console was located a few feet north of the house in a vacant lot.

Approximately 50 dosimeters were positioned in the house for measurements during this experiment. At least two dosimeters were placed at each position, and their readings were averaged to obtain the dose at that point. The dosimeters were placed in paper cups attached to strings hung from aluminum stands, as shown in Fig. 3.8.

The total time for setting up the experiment was approximately 6 hr; the total exposure time was 2.4 hr; and total time for taking down the equipment was 2.5 hr. One hour before the actual test began, the ionization chambers were charged and placed in selected positions inside the house. At approximately the same time, a dummy source was pumped through the tubing to assure that no obstructions were present and that the total MRMU system was functioning properly.

The use of the 191-mc Co^{60} source eliminated the need for evacuation of nearby neighbors. The edge of the test area was monitored with film badges and dosimeters; the total integrated dose 15 ft from the outer edge of the test area was less than 5 mr. Access to the test area was limited and controlled during the exposure.

REFERENCES

1. Z. G. Burson et al., Evaluation of the Fallout Protection Afforded by Brookhaven National Laboratory Medical Research Center, Report CEX-60.1, October 1961.
2. Z. Burson and H. Borella, Experimental Evaluation of the Radiation Protection Provided by an Earth-covered Shelter, Report CEX-60.6 (in preparation).

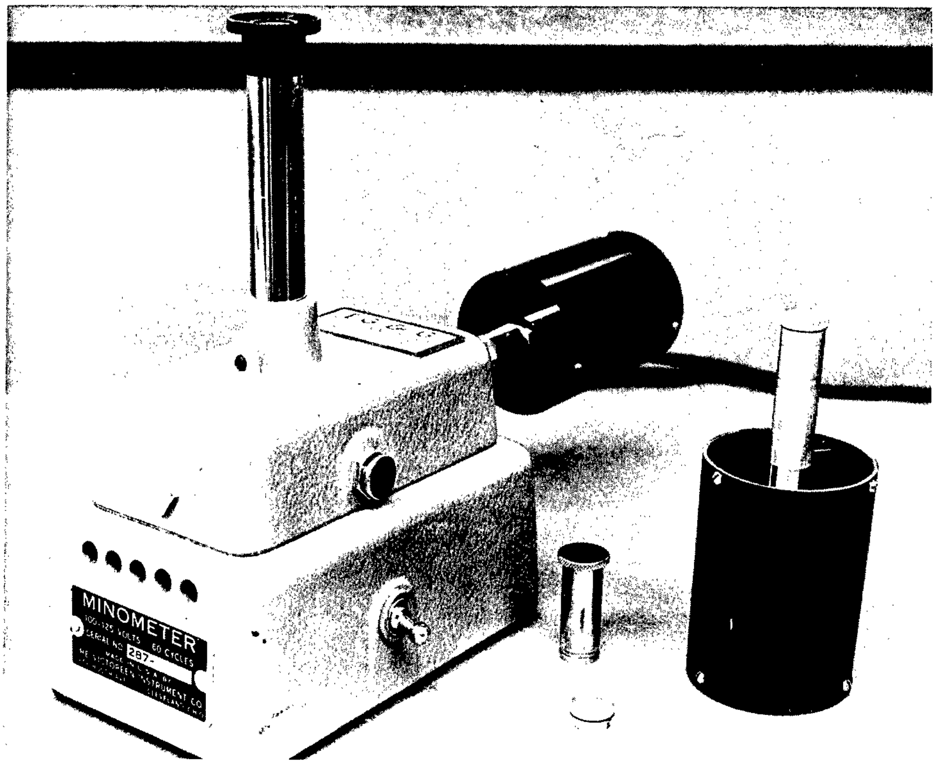

Fig. 3.3—Dosimeters and charger-reader.

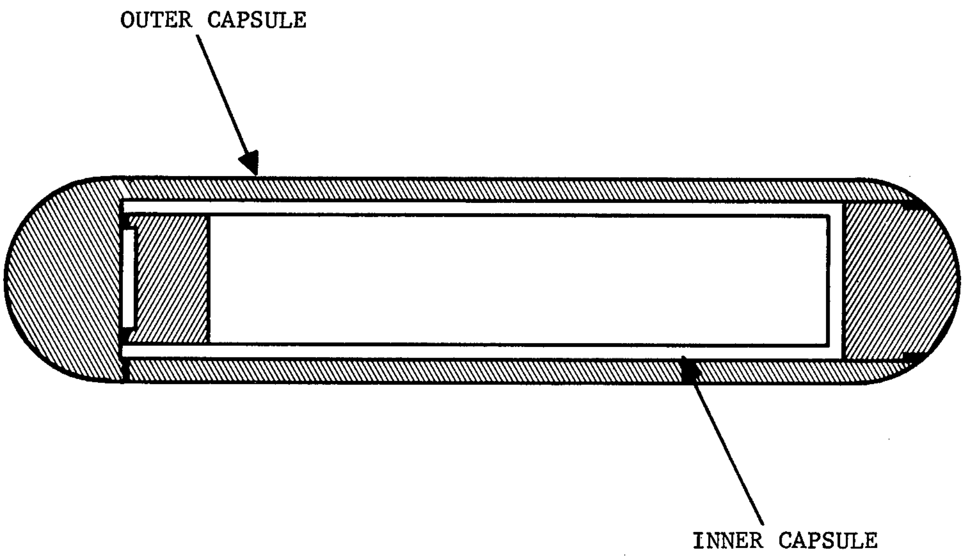

Fig. 3.4—Cutaway view of Co^{60} container.

Fig. 3.5 — Tubing layout on roof.

Fig. 3.6 — Tubing layout on roof and surrounding grounds.

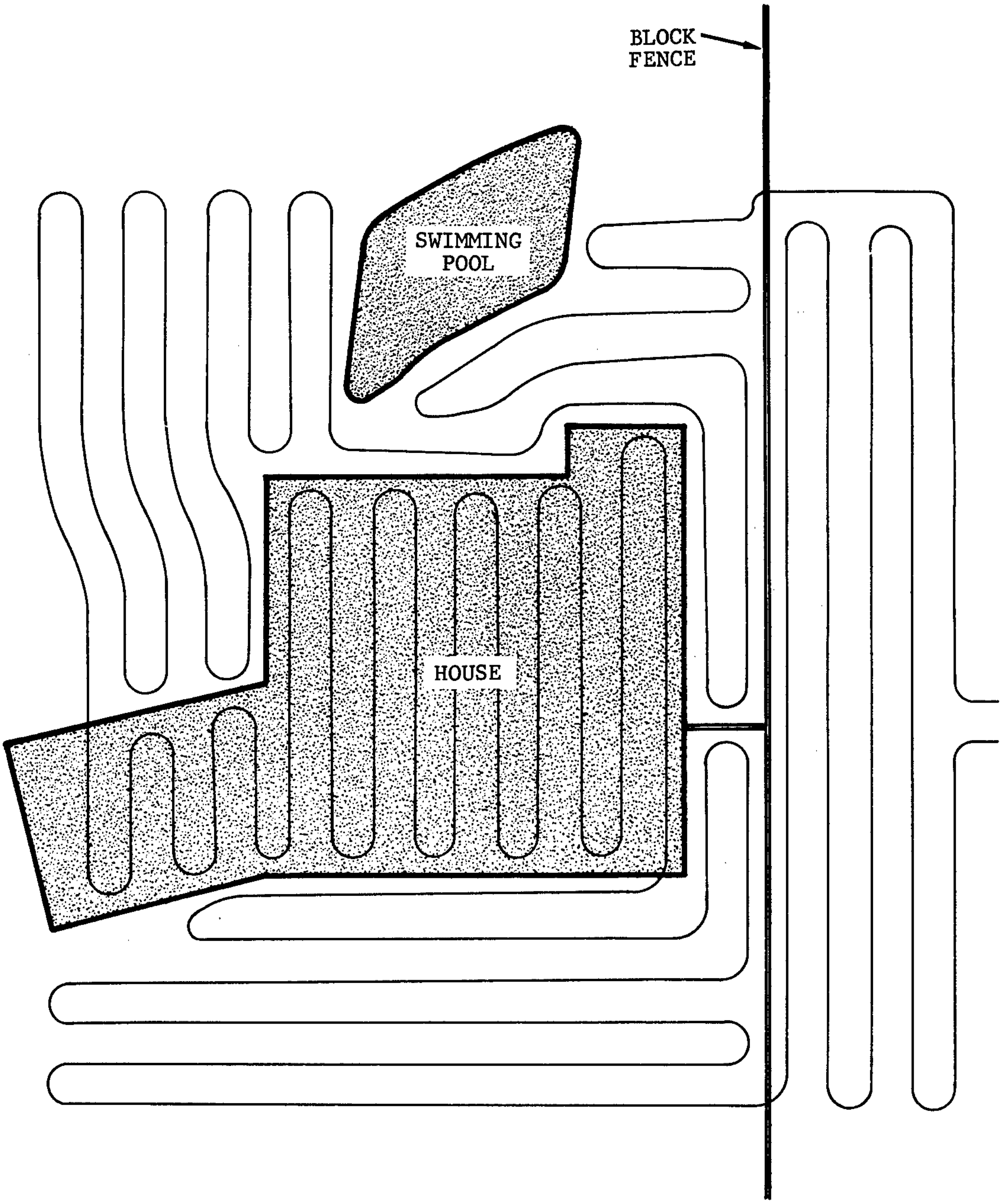

Fig. 3.7 — Tubing layout.

Fig. 3.8—Dosimeter positioning.

Chapter 4

PRESENTATION OF DATA

Data were taken at different heights above the floor at selected positions throughout the house. At each point the dosimeter readings were averaged, and the average value was corrected for leakage, temperature, pressure, and minometer calibration and normalized to give the dose rate in milliroentgens per hour at a source density of 1 (mr/hr)/(mc/sq ft) at standard temperature and pressure.

A floor plan of the house, showing dosimeter position numbers, is presented in Fig. 4.1. The normalized dose data at different heights above the floor and at various positions throughout the house are presented in Table 4.1.

TABLE 4.1 — DOSE RATES INSIDE HOUSE

	Dose rate*		
Position	At 2 ft	At 4 ft	At 6 ft
1	68	75	
2	52	69	
3		63	
4		61	
5		64	
6		95	
7		117	
8		63	73
9		65	88
10		77	95

*Normalized to milliroentgens per hour per millicurie per square foot.

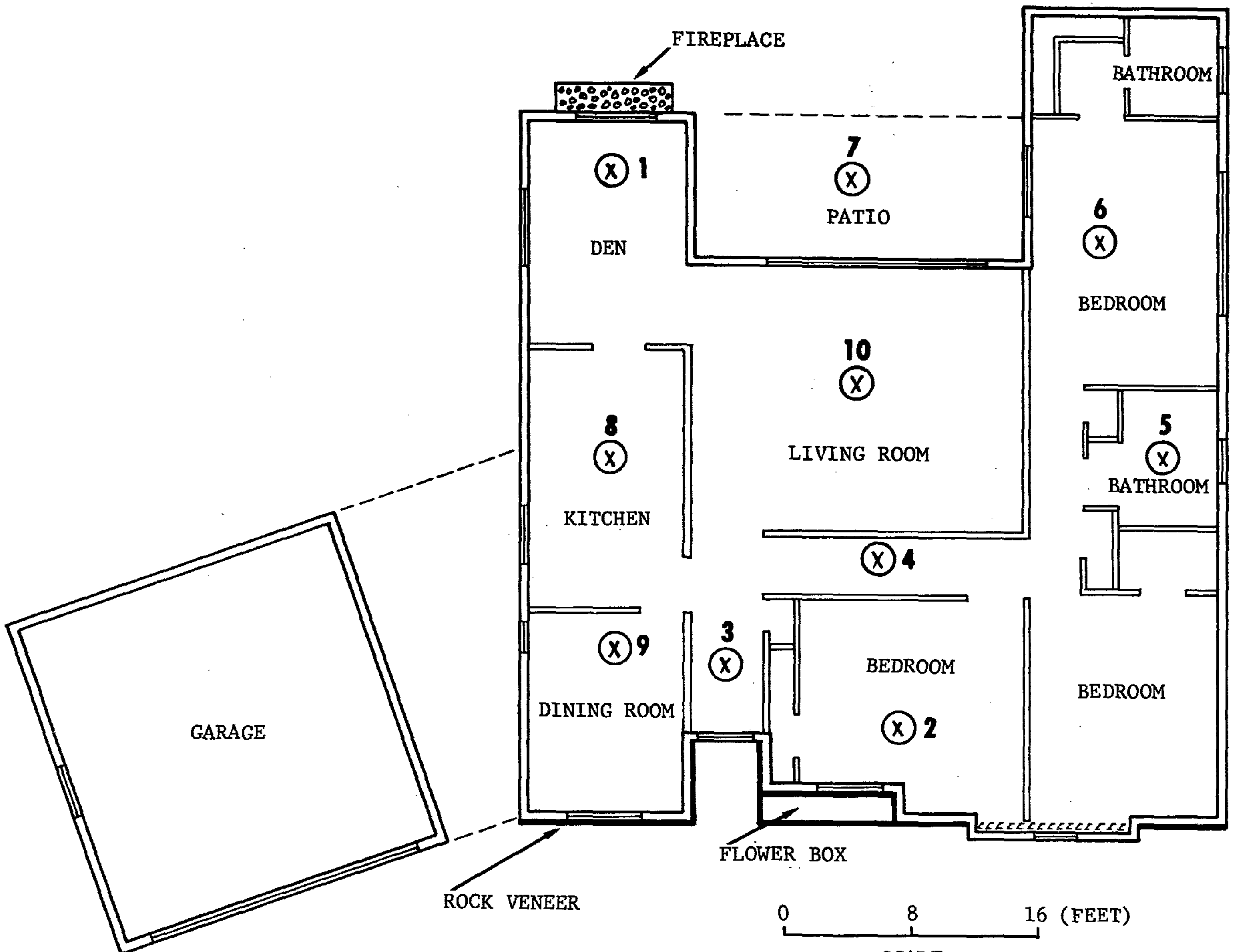

Fig. 4.1—Floor plan with dosimeter position numbers.

Chapter 5

ANALYSIS AND CONCLUSIONS

5.1 NORMALIZATION

All the experimental data were normalized to a standard source density so that the results could be evaluated properly. After the dosimeter readings were corrected for leakage, temperature, and calibration, they were then normalized by multiplying the corrected readings D_c (in milliroentgens) by the total area A (in square feet) over which the tubing was distributed, and dividing by the exposure time T (in hours) and by the source strength S (in millicuries). Accordingly,

$$\text{Normalized dose rate} = \frac{D_c \times A}{T \times S}$$

In this test A = 11,500 sq ft, T = 2.442 hr, and S = 191 mc.

The resulting dose rate at a particular point is then the same as it would be if the same area were contaminated by Co^{60} to a source density of 1 mc/sq ft.

5.2 PROTECTION FACTORS

Protection factors at different positions in the house were calculated from Eq. 2.5. The value of D_1 was found to be 270 (mr/hr)/(mc/sq ft). The protection factor was obtained by dividing the value of D_1 by the normalized data (values of R and G_1 measured together). These factors, at a height of 4 ft above the floor, were plotted on a floor plan (Fig. 5.1). The factors, measured at different heights above the floor, are also listed in Table 5.1.

TABLE 5.1 — PROTECTION FACTORS

	Height		
Position	2 ft	4 ft	6 ft
1	4.0	3.6	
2	5.2	3.9	
3		4.3	
4		4.4	
5		4.2	
6		2.8	
7		2.3	
8		4.3	3.7
9		4.2	3.1
10		3.5	3.8

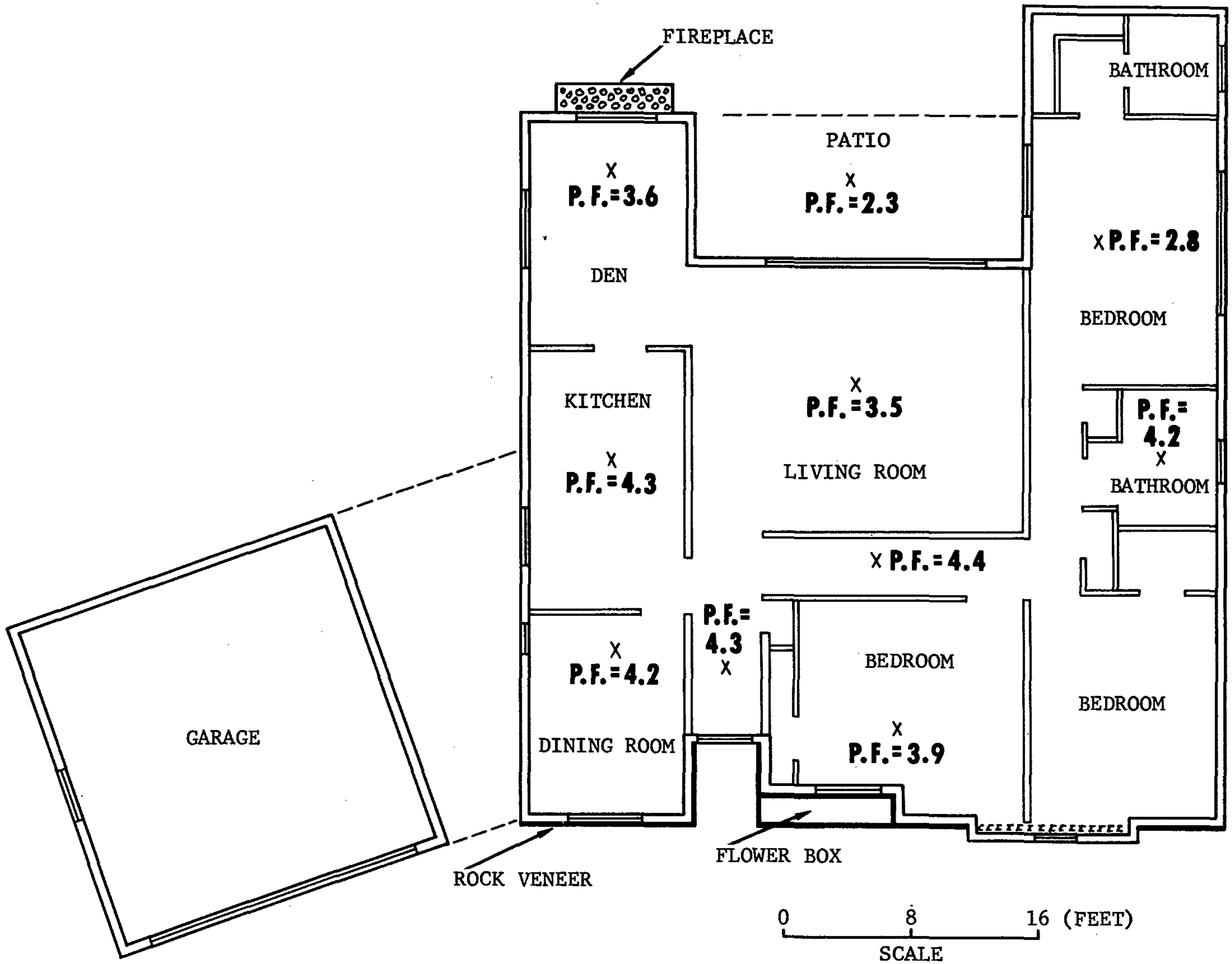

Fig. 5.1—Floor plan showing protection factors.

5.3 DISCUSSION AND GENERAL CONCLUSIONS

Theoretical calculation of a fallout protection factor is difficult because of the many unpredictable effects associated with a fallout situation. However, despite these unpredictable effects (including nonuniformly contaminated areas, the accumulation of fallout on trees and gutters, different shielding materials, internal rooms and equipment, ground contours, block fences, neighboring houses, and complicated shielding geometry), protection factors can be found rather simply by the method presented in this report. In addition, the difference in protection factors from point to point throughout the house can be compared in relation to the constructional characteristics of the structure.

Protection factors were determined by simulating fallout radiation above and immediately surrounding the house and by measuring the radiation level within. Radiation from distant fences and neighboring houses undoubtedly would affect the protection factors. If this attenuated radiation were considered, the protection factors would be higher than those presented in this report. However, fallout on trees and roofs of nearby buildings would tend to lower these protection factors. As a result the protection factors presented here are considered to be sufficiently accurate to meet the objectives of this study.

The protection factors varied from 2.8 to 4.4 throughout the house, the maximum being found in the hallway near the center of the house. In general, the protection factors were slightly better along the front of the house than in the rear, apparently because of the rock veneer on the front side. The protection factor in the den, which was about 4 ft from the large fireplace, was 3.3. The protection factor in the bathroom was 4.2, as compared to 2.8 in an adjacent bedroom, indicating that, in general, small rooms may offer more protection than large rooms because of additional shielding offered by more walls. However, in this particular case, the increased protection in the bathroom may have been partially due to heavier construction of the exterior bathroom wall, as compared to the adjacent bedroom, and to a more favorable orientation of the bathroom providing fewer sides of the room exposed to radiation on the ground. Even though the kitchen was a large room, the protection factor was relatively high. Kitchen appliances and shelved canned goods undoubtedly attenuated a portion of the radiation entering the kitchen. The patio was outside, but, since it was shielded on three sides and was beneath a low roof, it had a protection factor of 2.3.

These protection factors can be compared with those measured in Oak Ridge, Tenn., under similar conditions.[1] They are essentially the same as those in houses with similar structural characteristics.

The test was performed rapidly, easily, safely, and directly, with no unusual incidents occurring. Valid data were obtained even though the strength of the radioactive source was sufficiently low that even immediate neighbors did not have to be disturbed.

REFERENCE

1. T. D. Strickler and J. A. Auxier, Experimental Evaluation of the Radiation Protection Afforded by Typical Oak Ridge Homes Against Distributed Sources, Report CEX-59.13, April 1960.

CIVIL EFFECTS TEST OPERATIONS REPORT SERIES (CEX)

Through its Division of Biology and Medicine and Civil Effects Test Operations Office, the Atomic Energy Commission conducts certain technical tests, exercises, surveys, and research directed primarily toward practical applications of nuclear effects information and toward encouraging better technical, professional, and public understanding and utilization of the vast body of facts useful in the design of countermeasures against weapons effects. The activities carried out in these studies do not require nuclear detonations.

A complete listing of all the studies now underway is impossible in the space available here. However, the following is a list of all reports available from studies that have been completed. All reports listed are available from the Office of Technical Services, Department of Commerce, Washington 25, D. C., at the prices indicated.

CEX-57.1 ($0.75)	The Radiological Assessment and Recovery of Contaminated Areas, Carl F. Miller, September 1960.
CEX-58.1 ($2.75)	Experimental Evaluation of the Radiation Protection Afforded by Residential Structures Against Distributed Sources, J. A. Auxier, J. O. Buchanan, C. Eisenhauer, and H. E. Menker, January 1959.
CEX-58.2 ($0.75)	The Scattering of Thermal Radiation into Open Underground Shelters, T. P. Davis, N. D. Miller, T. S. Ely, J. A. Basso, and H. E. Pearse, October 1959.
CEX-58.7 ($0.50)	AEC Group Shelter, AEC Facilities Division, Holmes & Narver, Inc., June 1960.
CEX-58.8 ($1.00)	Comparative Nuclear Effects of Biomedical Interest, Clayton S. White, I. Gerald Bowen, Donald R. Richmond, and Robert L. Corsbie, January 1961.
CEX-58.9 ($1.25)	A Model Designed to Predict the Motion of Objects Translated by Classical Blast Waves, I. Gerald Bowen, Ray W. Albright, E. Royce Fletcher, and Clayton S. White, June 1961.
CEX-59.1 ($0.60)	An Experimental Evaluation of the Radiation Protection Afforded by a Large Modern Concrete Office Building, J. F. Batter, Jr., A. L. Kaplan, and E. T. Clarke, January 1960.
CEX-59.4 ($1.25)	Aerial Radiological Monitoring System. I. Theoretical Analysis, Design, and Operation of a Revised System, R. F. Merian, J. G. Lackey, and J. E. Hand, February 1961.
CEX-59.13 ($0.50)	Experimental Evaluation of the Radiation Protection Afforded by Typical Oak Ridge Homes Against Distributed Sources, T. D. Strickler and J. A. Auxier, April 1960.
CEX-59.14 ($1.75)	Determinations of Aerodynamic-drag Parameters of Small Irregular Objects by Means of Drop Tests, E. P. Fletcher, R. W. Albright, V. C. Goldizen, and I. G. Bowen, October 1961.
CEX-60.1 ($1.75)	Evaluation of the Fallout Protection Afforded by Brookhaven National Laboratory Medical Research Center, H. Borella, Z. Burson, and J. Jacovitch, February 1961.
CEX-62.01 ($0.50)	Technical Concept—Operation Bren, J. A. Auxier, F. W. Sanders, F. F. Haywood, J. H. Thorngate, and J. S. Cheka, January 1962.